Test beam Studies of a GEM-Based Time Projection Chamber

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IEEE - NSS
Rome, 20/10/2004
ILC/TESLA – Time Projection Chamber

In the Technical Design Report of the TESLA project a large time projection chamber is foreseen as a main tracker.

Sensitive volume
inner/outer radius:  36.2/161.8 cm
overall length:     2*250 cm

radiation length to outer fieldcage:  3%
favored gas mixture Ar:CH₄:CO₂ 93-5-2

Performance
spatial resolution at 10 / 200cm
in r-ϕ-plane       70/190μm
in z-plane         0.6/1mm
momentum resolution |cos θ|<0.75/~0.9
  1.4 / 3.2 * 10⁻⁴ c/GeV
dE/dx resolution  4.3% for 200 pad rows
Gas Electron Multiplier

- ion-feedback is strongly reduced
  => continuous running is possible
- small pitch between holes
  => much reduced ExB-effects
- no preference in geometry due to wire
  => all readout geometries are possible
- no ion-tail => fast signal
  => good for double track resolution (z)
- direct signal smaller in transversal width
  => good for double track resolution (r-φ)
- mechanically more stable
- separation of gas amplification and readout geometries
The Prototype

Drift volume: length 25cm
inner diameter 20cm
Gas amplification: 2 GEMs 60/70/140
Readout electronic: modified STAR-FEE

Chamber consists of 3 parts:
cathode,
Multi layers field cage,
readout area.
All parts can easily be replaced.
Reconstruction and Analysis

JAVA-based reconstruction and analysis tool has been developed

- proj. x-y
- proj. t-x
- proj. t-y

+ display of signals
+ inversion of signal and pedestal correction
+ reconstruction and analysis of clusters (Center Of Gravity)
+ reconstruction and analysis of tracks (linear and parabolic regression)

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time development of different pads
Test beam area at DESY

5.2 GeV electron beam
Low intensity spill every 317 ms

Longitudinal beam width
Vertical beam width

Limited by scintillator trigger
Drift time

Dipole-field of 1T
Aperature 55cm
Gas choice

To reduce the transverse diffusion the following choices were made:

- Gas: $\text{Ar} : \text{CH}_4 \ 95:5$
- Electric field: $60 \text{ V/cm}$
- Magnetic field: $1 \text{T}$

Comparison test beam – TESLA-TDR

<table>
<thead>
<tr>
<th>Gas</th>
<th>$\text{Ar} : \text{CH}_4 \ 95:5$</th>
<th>$\text{Ar} : \text{CH}_4 : \text{CO}_2 \ 93:5:2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-field</td>
<td>$60 \text{ V/cm}$</td>
<td>$240 \text{ V/cm}$</td>
</tr>
<tr>
<td>B-field</td>
<td>$1 \text{T}$</td>
<td>$4 \text{T}$</td>
</tr>
<tr>
<td>Drift vel.</td>
<td>$3.85 \text{ cm/µs}$</td>
<td>$4.5 \text{ cm/µs}$</td>
</tr>
<tr>
<td>Transv. diff.</td>
<td>$115 \mu\text{m/√cm}$</td>
<td>$72 \mu\text{m/√cm}$</td>
</tr>
<tr>
<td>Long. diff.</td>
<td>$550 \mu\text{m/√cm}$</td>
<td>$285 \mu\text{m/√cm}$</td>
</tr>
</tbody>
</table>
The noise challenge

Due to small magnet aperture:
Long flatband cables for connecting readout board and FEE
=> increased noise
Long rectangular pads

pads are 1.27*12.5mm²
arranged in 8 rows of 32 pads each

Tested in various environments:
e.g. a 5T magnetic field at DESY, Hamburg

transv. spatial resolution versus drift
distance and inclination of track

Ar : CH₄ : CO₂ 93:5:2

see also poster N16-70
Long rectangular pads

Transverse spatial resolution

Longitudinal spatial resolution

Drift distance: 17.5 cm (45 cm)
Underlying systematics

Effective gas gain and track inclination $\alpha$ have strong influence on transverse spatial resolution.

To include fluctuations in these two parameters, systematic errors of 15 $\mu$m have been included in the following plots.
Rectangular pads

Pad geometry suggested in the TESLA-TDR

2*6mm² give a total of 0.75*10⁶ channels for each TPC-endcap
Rectangular pads

pad geometry suggested in the TESLA-TDR
2*6mm² give a total of 0.75*10⁶ channels for each TPC-endcap

… if diffusion becomes too small, only one pad is hit
=> worse spatial resolution
Staggered rectangular pads

Pads have the same shape and size (2*6mm²), but every second row is shifted by half a pitch.
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Staggered rectangular pads

- Drift = 7.5 cm
- Drift = 10 cm
- Drift = 17.5 cm

$\alpha = 0^\circ$
$\alpha = 4.3^\circ$

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Staggered rectangular pads

![Graph showing transverse spatial resolution vs. drift distance in cm]
Due to geometrical reasons an intrinsic charge sharing is expected.
rhombus pads

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Fitting a double Gauss-function

- **drift = 10 cm**
- **drift = 12.5 cm**
- **drift = 17.5 cm**

- **$\alpha = 0^\circ$**
- **$\alpha = 2.6^\circ$**
- **$\alpha = 4^\circ$**

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Transverse spatial resolution of “rhombus” with double Gauss-functions

![Graph showing transverse spatial resolution vs. drift distance with single and double Gauss-functions](image.png)
Due to geometrical reasons an intrinsic charge sharing is expected.
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Due to geometrical reasons an intrinsic charge sharing is expected.
combs
combs
“3+1”

alternating long and short pads
⇒ reduced number of channels
⇒ thinner pads can be used

1.33* 6mm$^2$ and
1.33*18mm$^2$

During reconstruction:
charge of long pads was split
into 3 short pads according to the
charge of 6 adjacent short pads.
“3+1”
Various pad geometries have been tested and transverse spatial resolution could be improved in the short drift region. Better algorithms promise further improvements – especially with staggered rows.

<table>
<thead>
<tr>
<th>geometry</th>
<th>single Gauss</th>
<th>double Gauss</th>
</tr>
</thead>
<tbody>
<tr>
<td>rectangular</td>
<td>260µm</td>
<td>-</td>
</tr>
<tr>
<td>staggered</td>
<td>330µm</td>
<td>230µm</td>
</tr>
<tr>
<td>rhombus</td>
<td>360µm</td>
<td>230µm</td>
</tr>
<tr>
<td>chevrons</td>
<td>300µm</td>
<td>-</td>
</tr>
<tr>
<td>combs</td>
<td>350µm</td>
<td>-</td>
</tr>
<tr>
<td>“3+1”</td>
<td>218µm</td>
<td>-</td>
</tr>
</tbody>
</table>
The authors would like to thank:

• Norbert Meyners for making this beam test possible.
• The FLC-group of DESY and especially T. Behnke, P. Wienemann and M. Ball for contributing in many different ways.
• D. Karlen for modifying the electronics.
• T. Barvich for solving all of the mechanical problems.